Beam Test Facility

Response of an active pixel sensor (APS) detector to 1.5 GeV electrons

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INTRODUCTION

There is tremendous interest in ultra-relativistic heavy ion physics to measure open charm – particles with the charmed quark. Charmed particles provide a more direct link with the early hot Quark Gluon phase of the Nucleus-Nucleus interaction. Most of the particles currently available for measurement in these experiments primarily reflect the later hadronization phase of the interaction. Due to their larger mass, charmed quarks only can be produced during the hot partonic phase, so they provide a more direct connection to this early stage without contamination from the later cooler phase. With the help of a new inner high-resolution vertex detector, we can measure the charm content through the D meson decay channel.

Accomplishing this requires a vertex detector with very good pointing resolution. This means the vertex detector must be very thin to reduce multiple scattering. It also means the vertex detector must have excellent two hit resolution so that it can be placed very close to the interaction without being compromised by the huge particle numbers, i.e. it must have a high pixel density.

PREVIOUS WORK

Experiments that are under construction at the Large Hadron Collider at CERN use Silicon Pixel diode wafers bump bonded to the readout electronic chips. [1] This approach does not meet the thinness and high pixel density requirements for the STAR experiment [2] at Brookhaven National Laboratory. An alternative technology that addresses these issues is the integration of special amplifier and logic structures required for readout directly into the high resistive silicon of the detector. Researchers have made some progress in this approach, but it will always be limited by the need for special processes. This approach increases the cost and mandates the complication of dealing with specialized foundries.

Work [3] at LEPSI in Strasbourg has demonstrated that Active Pixel Sensor (APS) technology in CMOS works very well for detecting minimum ionizing particles with a good signal to noise ratio. However, APS technology is in its infancy, so that we must study many issues to create a working high-resolution pixel detector.

TEST SETUP

We designed a prototype sensor array that includes an array of 128 by 128 pixels broken into four quadrants of 64 by 64 pixels. Each quadrant uses a different sensor structure and/or readout circuit. Each pixel is 20 by 20 microns in size, and the entire array is about 2.5 mm on a side. Quadrant 1 has a single diode to pick up the charge from the chip while quadrant 2 had four diodes. Due to the larger capacitance of quadrant 4, the signal size is less than quadrant 1. In this article, we will report on the results from quadrant 1.

We mounted the APS chip on a readout board and used a 2 MHz pipelined ADC, which digitized the data. A Xilinx XC3064A FPGA provided the control signals for reading out the APS chip and sent the data to a National Instruments PCI-DIO-32HS PCI interface located in a Macintosh G3 computer. A 16 K x 16 FIFO chip between the ADC and the DAQ interface provided an elasticity buffer to guarantee consistent readout timing.

While the ALS was in the storage ring mode, the booster was used to deliver 1.5 GeV electrons to our detector at a rate of 1 Hz. We put our detector at the end of branch line off the main booster-to storage ring (BTS) transfer line. There was about 20 cm of air between our detector and the last vacuum gate valve. We set the intensity of the beam so that each beam pulse provided on the order of 10 particles to our detector. The left graph of Fig. 1 shows the response of Quadrant 1 of the detector to one beam spill. This graph shows several easily identified electrons. The figure on the right shows the same detector when the beam was off.

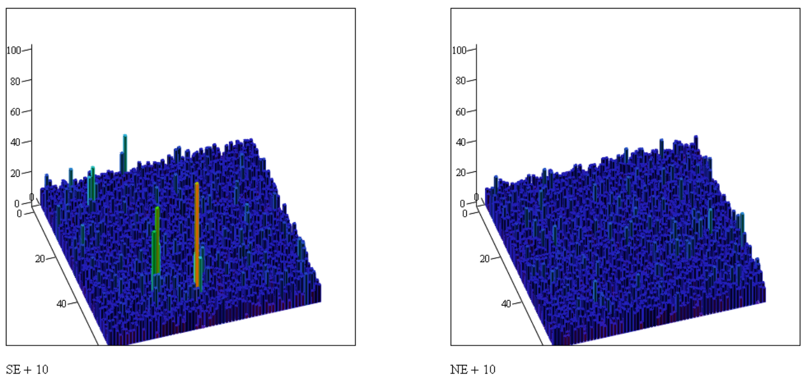

Figure 1. The graph on the left shows the response of the detector to 1.5 GeV electrons, while the graph on the right shows the results when the beam was turned off. Each rectangle represents on pixel on the chip. The height of each rectangle represents the energy deposited in each pixel.

RESULTS

To eliminate the noise introduced by resetting the chip, we used the correlated double sampling method to analyze the data. We reset the chip and then read out the value of the pixels one frame before the beam hit the detector, we then read the chip again and subtracted the two frames. The result is the charge deposited by electron beam plus the leakage current. We then subtracted a subsequent frame to eliminate the leakage current.

Figure 2 shows the energy normalized ADC spectrum for this run. The solid curve shows an absolute calculated energy assuming that all charge comes from the 8 μm epitaxial layer of the chip. The nose, which is 17 electrons, is subtracted from this spectrum. The fit is in excellent agreement with the expected result. The peak of the energy distribution is near 500 electrons. We are currently producing the next version of the chip and plan on testing it in the same ALS beam line.

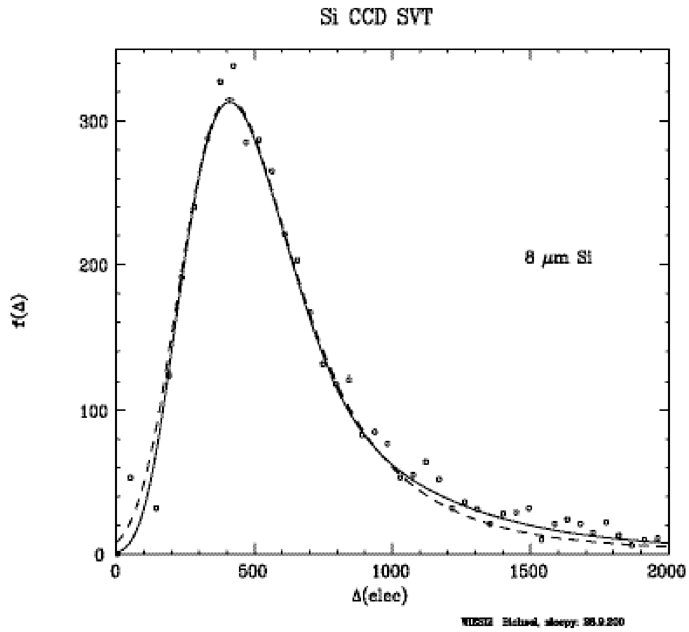

Figure 2. Prototype device test results fitted to a 1.5 GeV electron spectrum.

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